Agenda Item 5a

Memorandum

To: Water Supply Advisory Committee

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Date: 3/11/2015

Subject: Background information on climate variability and extended droughts

This memorandum provides technical information to support the Water Supply Advisory Committee (WSAC) understanding of the magnitude, severity, and frequency of the drought the Santa Cruz Water Department wants to be prepared to handle in the future. As discussed during the February WSAC meeting, climate variability is much larger than the variability seen during the 73 years of hydrologic record available for the Santa Cruz region. Keep in mind that seventy-three years is only a "blink of an eye" in historic time. In order to support WSAC decision-making, the Technical Team has developed this memorandum which includes:

- Summaries of several studies that show that the recent historical period was characterized by rainfall that was well above long-term averages. Therefore, the "worst" drought of that 73-year record may underestimate the drought event that Santa Cruz needs to prepare for.

- Confluence runs of a plausible drought that combines the 1976–1977 drought with the 1987–1992 drought to examine the effect of a longer, but not more severe, drought than seen in recorded history.

The Technical Team looks forward to addressing WSAC questions concerning information provided here as well as to receive additional instructions for gathering information to help ensure the community of Santa Cruz is prepared for the water supply risks associated with plausible future drought conditions.

Regional drought information from the climate literature

Recent evaluations of paleoclimate records and future climate model projections indicate that longer-term drought conditions have occurred in the past and are likely to occur again within the next century. In this section we review paleoclimate and climate change projection studies relevant to drought planning in California and the Santa Cruz region. Several publications, including some very recent ones, compare modern climate observations to historical records and to future climate projections.

Fritts (1991) shows that droughts in the Santa Cruz region were frequently much longer than three to eight years. Paleoclimate reconstruction for the California valleys show that precipitation from the 17th century until the 20th century was consistently below average 20th-century values, with long periods of relative drought and short periods of high rainfall. These data show that cycles of below-average precipitation have commonly lasted from 30 to 75 years (Fritts, 1991).

Other paleoclimate analyses, summarized in Fritts (1991), have concluded:

- "Realistic planning for the future might better center on seasonal climate and the larger variance of information in the smaller regions, rather than focusing exclusively on worldwide changes varying only on time scales of centuries to millennia" (p. 7).
- "The variability of precipitation was reconstructed to have been higher in the past three centuries than in the present" (p. 7).
- "Lower variability occurred in twentieth-century precipitation. Reconstructions of this kind should be used to extend the baseline information on past climatic variations so that projections for the future include a more realistic estimate of natural climatic variability than is available from the short instrumental record" (p. 8).

A recent publication by Cook et al. (2015) compares paleoclimate drought records with future predicted conditions based on climate change models. The authors compared anticipated future drought severity to past droughts for the last 1,000 + years. Past drought severity was obtained from the tree-ring record, and future anticipated conditions were obtained from climate modeling. The authors found that drought conditions in the coming century are likely to be as bad or worse than the most severe historical droughts in the region, with severe dry periods lasting several decades (20–30 years). In some cases, winter precipitation may increase, but gains in water during that period will most likely be lost due to hotter, drier summers and greater evaporative demand. Figure 1 shows the comparison between moisture balance in the historical record (brown lines) and future climate models (colored lines beginning from mid-1800s) in the Southwest region.

Other recent studies linking climate change, precipitation changes, and drought conditions have found that warming temperatures greatly increase drought risks in California (Diffenbaugh et al., 2015). Drought conditions are exacerbated when warm temperatures coincide with lower rainfall. As the climate warms, the probability that warm temperatures and low rainfall years co-occur increases; in fact, Diffenbaugh et al. (2015) evaluated a suite of climate models and found that climate change is increasing the probability that warm and dry years coincide to nearly 100% in future decades. Griffin and Anchukaitis (2014) evaluated the tree-ring record and concluded that the current drought in California (three years at the time of publication) is the most severe drought in the last 1,200 years. This study finds that precipitation during the drought has been anomalously low but not outside the range of natural variability. They conclude that the combination of record high temperatures and reduced precipitation are responsible for the drought's severity.

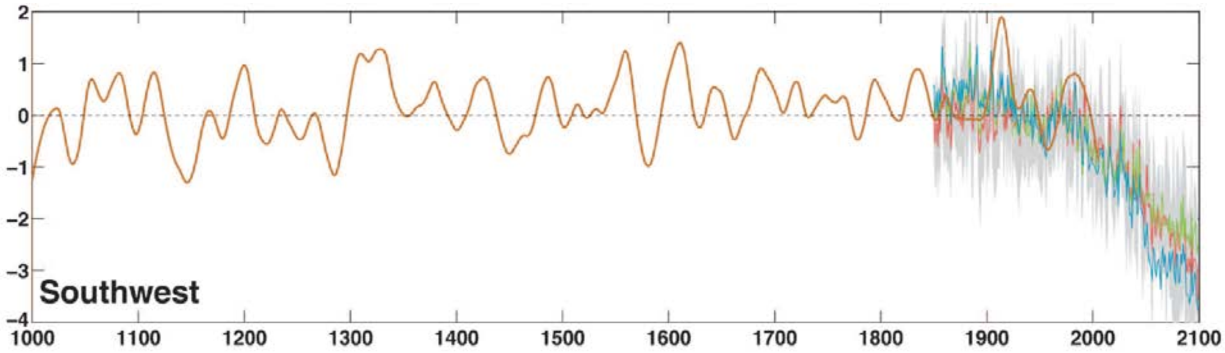

Figure 1. The observational North American Drought Atlas (NADA) Palmer Drought Severity Index (PDSI) series (brown) smoothed using a 50-year loess spline to emphasize the low-frequency variability in the paleo record. Model time series (PDSI, SM-30cm, and SM-2m) are the multi-model means averaged across the 17 DMIP5 models, and the grey shaded area is the multiple model interquartile range for model PDSI.

Source: Cook et al., 2015, Figure 1.

Because the "historical record" assumption used in the Baseline Scenario may not adequately identify the droughts the City of Santa Cruz may face in the future, and therefore needs to prepare for, this scenario defines an extended drought planning sequence that represents a discrete plausible future event that can guide water resource planning in Santa Cruz.

Rational for selection of an eight-year drought

The underlying assumption of identifying a drought that may occur in the future is that future weather and streamflows will differ from the past. However, we do not know exactly how they will differ (i.e., we know what severe droughts Santa Cruz experienced in the period of record but we do not know how much more severe a future drought might be). While we know the drought chosen should exceed past events in duration and/or severity, it must also be plausible (i.e., there must be a reasonable likelihood of its occurrence).

With this in mind, the extended drought planning sequence that the Technical Team has selected for analysis is an eight-year drought. The drought event begins with two years of weather and hydrology that match the historical 1976–1977 periods. The last six years mimic the 1987–1992 period, which was a longer but less severe historical drought. Note that although both portions of the drought-planning sequence are based on historical weather and hydrologic patterns, the assumption that one immediately follows the other is historically unprecedented.

Other California water suppliers, including the San Francisco Public Utilities Commission (SFPUC), the East Bay Municipal Utilities District, and the City of Santa Barbara, have pursued similar approaches. While the details have differed, each utility specified an extended drought sequence not reflected in its historical flow record. Each utility then used this extended drought to inform its resource planning and/or system operations. A short summary of the reasoning used by SFPUC and City of Santa Barbara are provided below.

San Francisco drought planning

Since the early 1990s, the SFPUC has used an 8½-year design drought for planning, which simulates conditions worse that any event SFPUC has ever experienced. SFPUC uses the design drought to plan for future urban demands and to ensure that they will be able to meet forecasted demand through a drought. In order to simulate a drought worse than any they had experienced, SFPUC designed the following drought sequence:

- A drought similar to the 1987–1992 drought experienced in the region
- A two-year period representing the 1976–1977 drought
- A six-month system recovery period.

SFPUC also feels confident about their design drought because staff believe it to be robust enough to account for anticipated future climate conditions. SFPUC selected the 8½-year design drought long before they began considering climate change, but recently they evaluated if climate change might influence the design drought. They evaluated several climate scenarios and changed the historical hydrologic inputs into their hydrology models to reflect potential future changes. Although this exercise was not done to directly assess the design drought, this climate change work has confirmed that the current design drought is sufficient to cover future climate conditions for the SFPUC system.

Santa Barbara drought planning

In their 2011 long-term water supply plan, Santa Barbara identified the ability to provide adequate water during an extended drought as the city’s fundamental water supply challenge. Santa Barbara is dependent on one primary reservoir – Lake Cachuma – for drinking water. A critical drought occurs when there are multiple, consecutive years of below-average rainfall, which causes substantially reduced flow in the Santa Ynez River and, thus, little or no inflow into Lake Cachuma.

Santa Barbara currently uses a 6-year critical drought scenario with an assumed drought recurrence of 30 years in their planning. This planning scenario was designed based on two key factors:

1. Supply during a critical drought was established using data from the 1947–1951 drought, with an additional hypothetical sixth year

2. Guidance from the State of California that instructs utilities without more accurate and comprehensive climate modeling to plan for a 20% increase in future drought frequency and duration (State of California, 2008)
   - This guidance led to the hypothetical sixth year in the critical-drought scenario, and an assumed drought recurrence of 30 rather than 40 years.

Based on the six-year critical drought scenario, Santa Barbara estimates that the long-term average annual predicted water delivery is 46% of the maximum amount of water any entity is entitled to request each year. One of the primary driving factors in this reduction is reduced precipitation falling as snow.

Santa Barbara manages droughts by reducing consumption, relying on groundwater supplies (which are small) and on water from the state distribution lines. The city also has a desalination plant, currently inactive, which can be reactivated if required (the desalination plant was recently permitted for reactivation). It takes five years for Lake Cachuma to be fully exhausted and over one year to reactivate the desalination plant. Figure 2 (see Figure 9 in City of Santa Barbara, 2011) illustrates how water supply will be allocated during the six-year critical drought used in planning.

Confluence modeling of system operation in extended droughts

Although an extended-drought planning sequence is just that, a planning tool, we must model its impacts to mimic as best we can how the city would actually operate the system if faced with such a drought. The first two years of our drought sequence duplicate the 1976–1977 historical experience. It therefore stands to reason that in those years, the city would operate the lake as we have been assuming in our modeling to this point, namely with rule curves that result in lake drawdown to 1,070 mg by the end of the 1977 water year.

Not only does this ensure consistency with our past *Confluence* modeling, but more importantly it reflects the realization that in the real world, system operators would have no way of knowing in those initial two years that a non-historical event is occurring. However, after that, we enter into new territory, where we know that we are in an extended drought and it is here that we must assume that the city starts to redeem its insurance policy by beginning to draw down the lake to zero.[1]

In sum, for modeling purposes, the extended drought sequence is divided into two portions, the first of which does not differ from the historical record, and the second of which goes beyond that record and thus merits extraordinary lake drawdown.

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[1] Actually, the lake is drawn down to 70 mg, which is the volume that is assumed to be physically inaccessible.

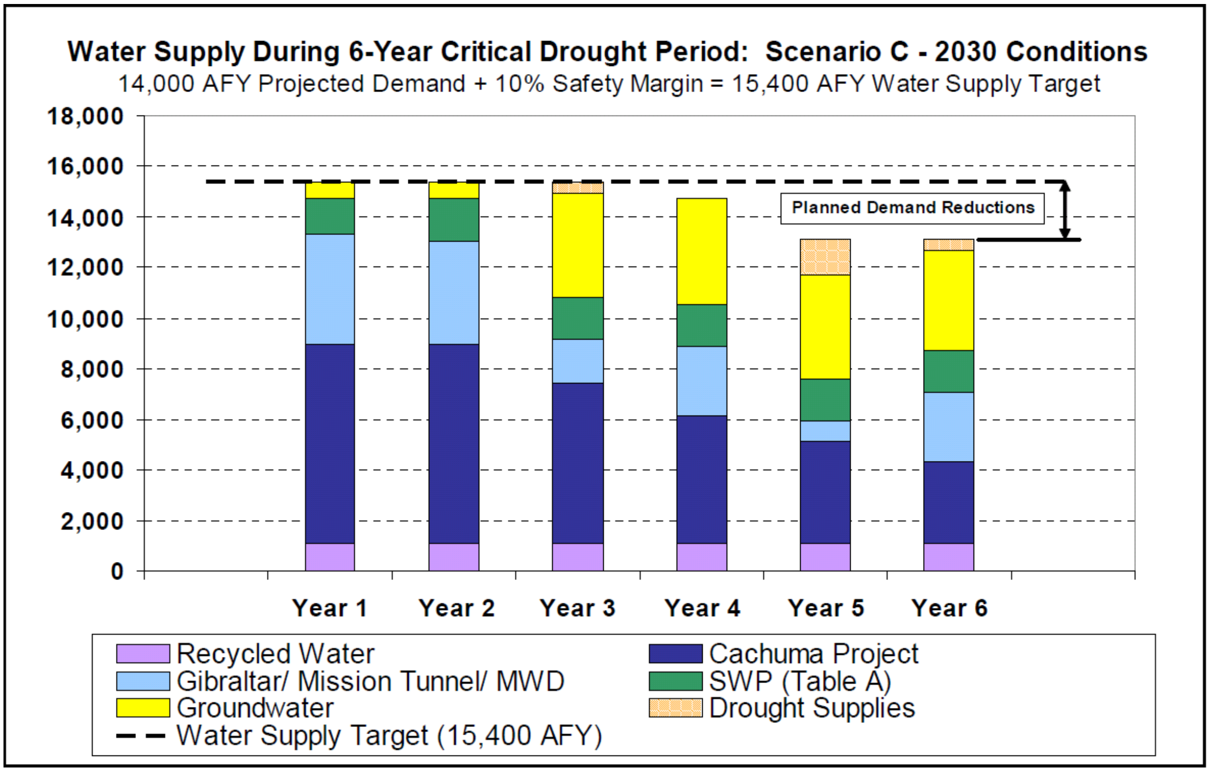

Figure 2. Water supply during six-year critical drought period.

Source: City of Santa Barbara, 2011, Figure 9.

Modeling results

The *Confluence* results that follow assume base interim 2020 projected demands. Results are shown for both city- proposed and DFG-5 fishery flows.

Figure 3 shows the modeled lake drawdown over the extended drought sequence. Assuming city-proposed flows, the lake is drawn down to the billion gallon minimum level at the end of the second (i.e., 1977) year. The lake then gets drawn down further in each subsequent drought year until it approaches full drawdown in the last two years. With DFG-5 flows, it is impossible to keep the lake above the billion gallon minimum at the end of the second year. After that, the lake stays low and is drawn down to within 150 mg of “empty” in four of the next five years before recovering to some extent as more abundant rains return in the winter of 1992.

Figures 4 and 5 show, respectively, the peak-season volumetric and percentage shortages that result over this extended drought, while Table 1 shows some key summary system reliability statistics.

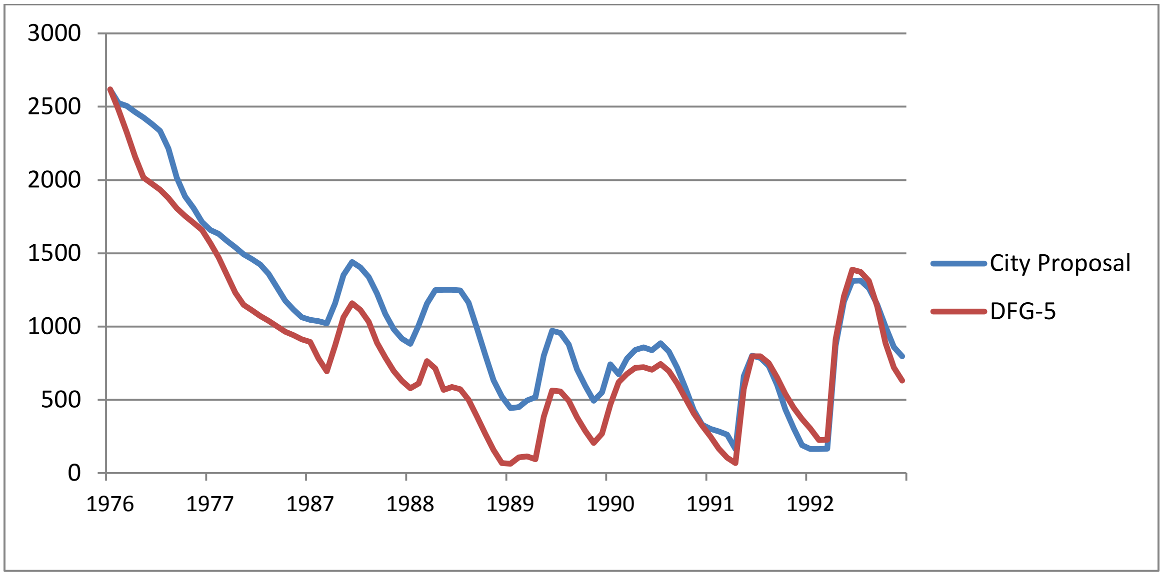

Figure 3. End of month lake levels (mg).

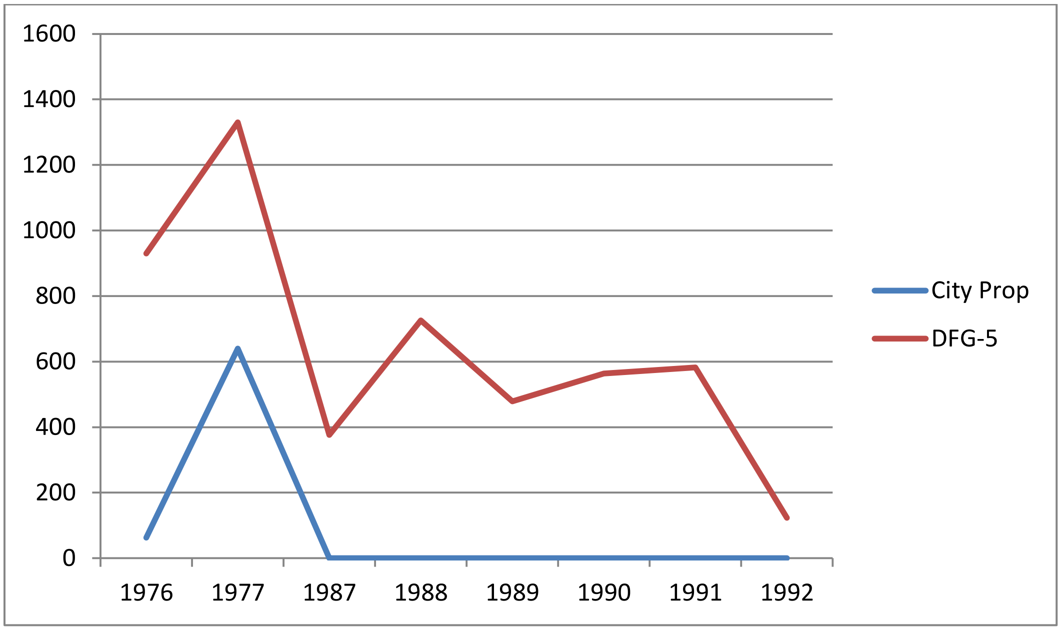

Figure 4. Peak-season shortages (mg).

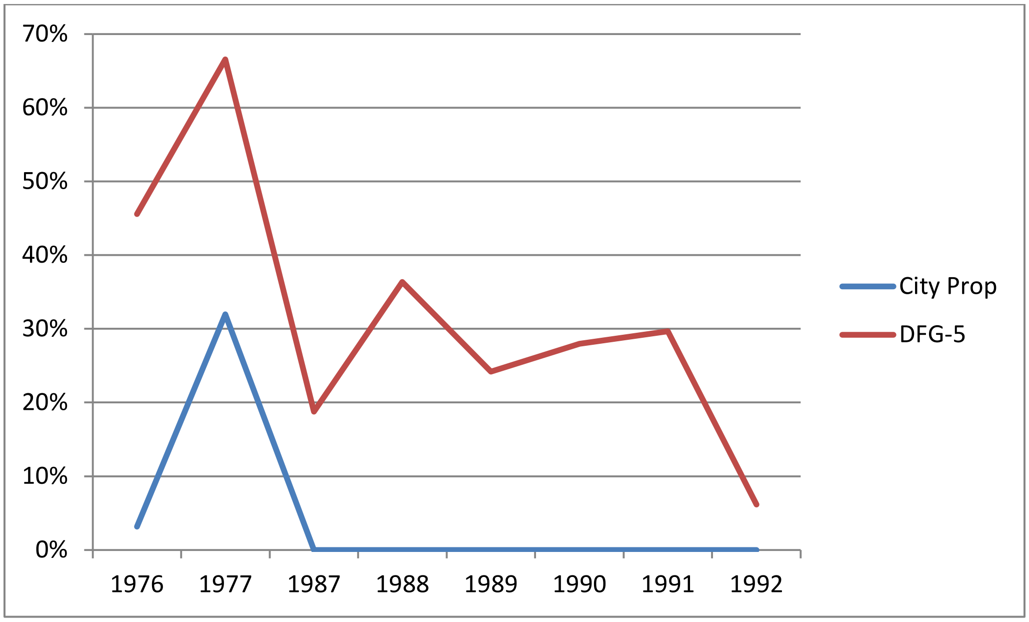

Figure 5. Peak-season shortages (%).

Table 1. Extended drought peak-season shortage statistics

	City proposal	DFG-5
Total 8-year (mg)	702	5,108
Average	4%	32%
Maximum	32%	67%
Minimum	0%	6%
Years > 20%	1	6

Assuming city-proposed flows, the only year of the extended drought in which the system experiences significant shortages is the second (i.e., 1977) year, when the shortage exceeds 30%. The picture is very different with DFG-5 flows. Significant system shortages persist throughout the sequence with more than five billion gallons of peak-season demand going unserved over the eight years. Peak-season shortages average more than 30%, with six of the eight years having shortages that exceed 20% (and one additional year just under that).

In sum, the ability of the current supply system to respond to this extended drought depends critically on the assumed outcome of the Habitat Conservation Plan negotiations with the California Department of Fish and Wildlife.

References

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